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(54) **EXHAUST AFTERTREATEMENT SYSTEM WITH CATALYTIC DEACTIVATION MONITORING**

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CPC ***F01N 3/208*** (2013.01)

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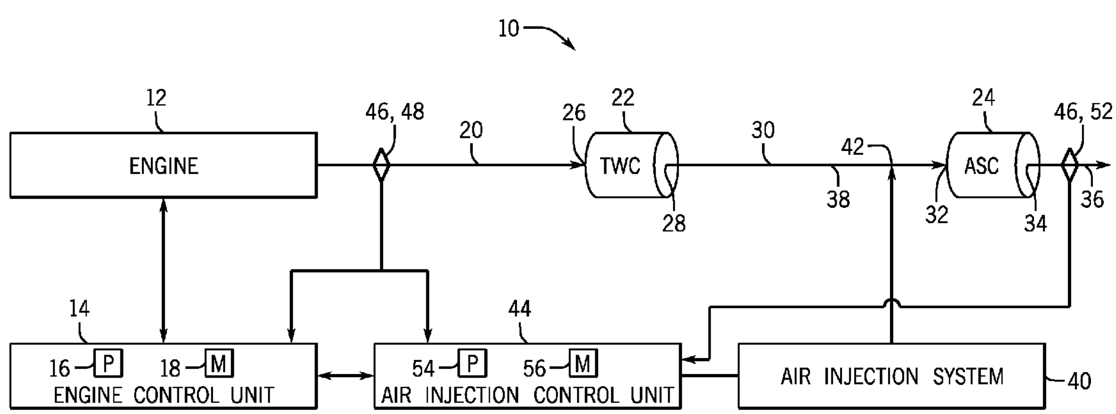
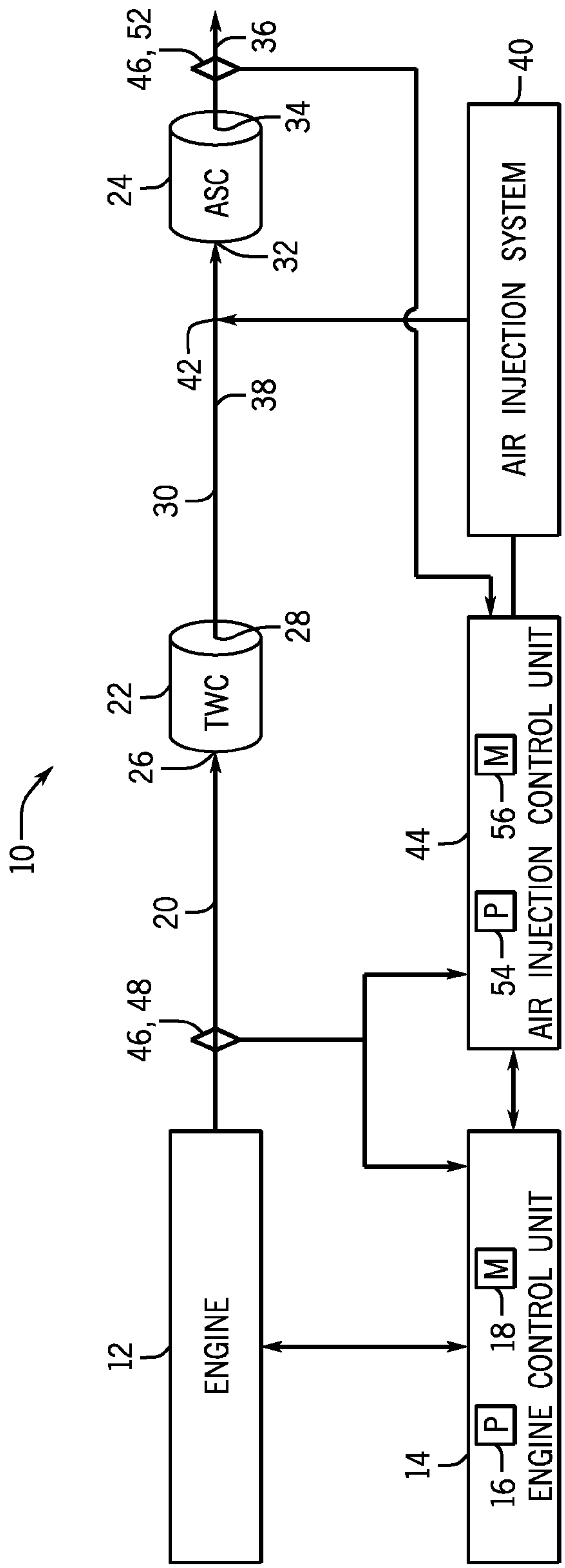
(57) **ABSTRACT**

A system includes a controller configured to determine if a combustion engine is operating under a desired rich fuel condition. The controller is also configured, if the combustion engine is operating under the desired rich fuel condition, to monitor a catalytic activity within an ASC assembly that converts NH_3 within treated exhaust gases from the combustion engine into N_2 to determine whether the catalytic activity has been deactivated in the ASC assembly.

16 Claims, 2 Drawing Sheets




ENGINE
ENGINE CONTROL UNIT
P
M
AIR INJECTION CONTROL UNIT
P
M
AIR INJECTION SYSTEM
TWC
ASC
10
12
14
16
18
20
22
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26
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30
32
34
36
38
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44
46, 48
46, 52
54
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FIG. 1

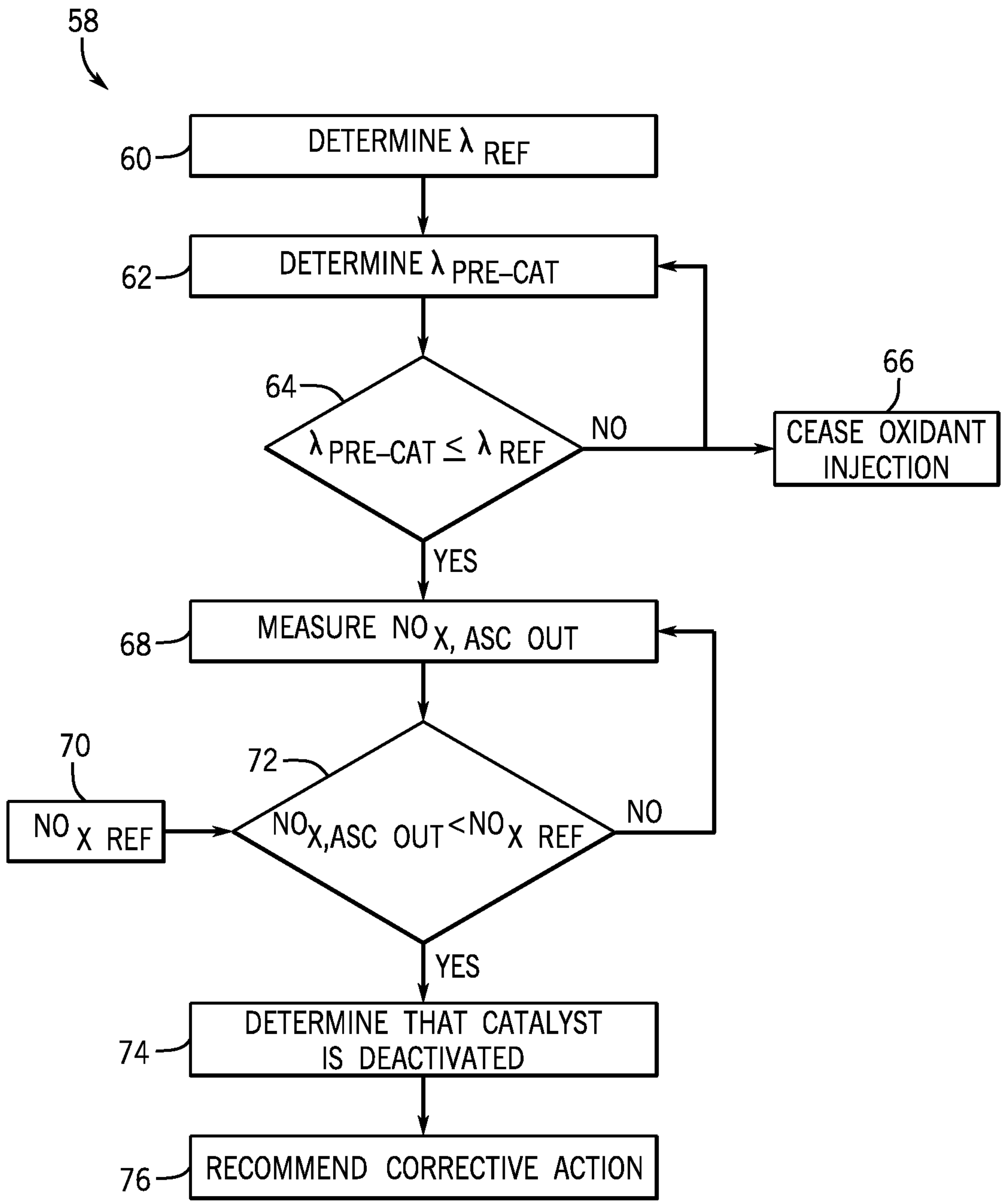
58
60
DETERMINE λ REF
62
DETERMINE λ PRE–CAT
64
λ PRE–CAT ≤ λ REF
NO
66
CEASE OXIDANT INJECTION
YES
68
MEASURE NO X, ASC OUT
70
NO X REF
72
NO X,ASC OUT < NO X REF
NO
YES
74
DETERMINE THAT CATALYST IS DEACTIVATED
76
RECOMMEND CORRECTIVE ACTION

FIG. 2

EXHAUST AFTERTREATEMENT SYSTEM WITH CATALYTIC DEACTIVATION MONITORING

BACKGROUND

The subject matter disclosed herein relates to an exhaust aftertreatment system for an internal combustion engine and, more specifically, to monitoring a component of the exhaust treatment system for catalytic deactivation.

Engines (e.g., internal combustion engines such as reciprocating engines or gas turbines) combust a mixture of fuel and air to generate combustions gases that apply a driving force to a component of the engine (e.g., to move a piston or drive a turbine). Subsequently, the combustion gases exit the engine as an exhaust, which may be subject to exhaust treatment (e.g., aftertreatment) systems that include one or more catalytic converters (e.g., three-way catalyst (TWC) assembly, ammonia slippage catalyst (ASC) assembly, etc.) to reduce the emissions of nitrogen oxides (NO_X), hydrocarbons (HC), and carbon monoxide (CO). However, as some of the catalysts of the catalytic converters age or become deactivated, the effectiveness of the catalysts at reducing emissions may decrease.

BRIEF DESCRIPTION

Certain embodiments commensurate in scope with the originally claimed invention are summarized below. These embodiments are not intended to limit the scope of the claimed invention, but rather these embodiments are intended only to provide a brief summary of possible forms of the invention. Indeed, the invention may encompass a variety of forms that may be similar to or different from the embodiments set forth below.

In accordance with a first embodiment, a system includes an exhaust aftertreatment system configured to treat emissions from a combustion engine. The exhaust aftertreatment system includes a first catalyst assembly configured to receive a fluid and to convert ammonia (NH_3) within the fluid into nitrogen (N_2), wherein the first catalyst assembly has an inlet and an outlet. The exhaust aftertreatment system also include at least one oxygen (O_2) sensor disposed upstream of the inlet of the first catalyst assembly and configured to determine a concentration of O_2 in exhaust gases generated by the combustion engine. The exhaust aftertreatment system further includes at least one NO_X sensor disposed downstream of the outlet of the first catalyst assembly and configured to measure a concentration of NO_X in the fluid exiting the outlet of the first catalyst assembly. The exhaust aftertreatment system yet further includes a controller configured to receive a first signal from the at least one NO_X sensor representative of the concentration of NO_X in the fluid exiting the outlet of the first catalyst assembly and a second signal from the at least one O_2 sensor representative of the concentration of O_2 in the exhaust gases generated by the combustion engine. The controller is also configured to determine whether the catalytic activity has been deactivated in the first catalyst assembly.

In accordance with a second embodiment, a system includes a controller configured to determine if a combustion engine is operating under a desired rich fuel condition. The controller is also configured, if the combustion engine is operating under the desired rich fuel condition, to monitor a catalytic activity within an ASC assembly that converts NH_3 within treated exhaust gases from the combustion engine into N_2 to determine whether the catalytic activity has been deactivated in the ASC assembly.

In accordance with a third embodiment, a system includes an exhaust aftertreatment system configured to treat emissions from a combustion engine. The exhaust aftertreatment system includes a TWC assembly having a first inlet. The exhaust aftertreatment system also includes an ASC assembly configured to receive treated exhaust gases from the TWC assembly and to convert NH_3 within the treated exhaust gases into N_2, wherein the ASC assembly has a second inlet and an outlet. The exhaust aftertreatment system further includes at least O_2 sensor disposed upstream of the first inlet of the TWC assembly and configured to determine a concentration of O_2 in exhaust gases generated by the combustion engine. The exhaust aftertreatment system yet further includes at least one NO_X sensor disposed downstream of the outlet of the ASC assembly and configured to measure a concentration of NO_X in the treated exhaust gases exiting the outlet of the ASC assembly. The exhaust aftertreatment system still further includes a controller configured to determine if the combustion engine is operating under a desired rich fuel condition, and, if the combustion engine is operating under the desired rich fuel condition, to monitor catalytic activity within the ASC assembly that converts NH_3 within the treated exhaust gases into N_2 to determine whether the catalytic activity has been deactivated in the ASC assembly.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other features, aspects, and advantages of the present invention will become better understood when the following detailed description is read with reference to the accompanying drawings in which like characters represent like parts throughout the drawings, wherein:

FIG. **1** is a schematic diagram of an embodiment of an exhaust treatment (e.g., aftertreatment) system coupled to an engine; and

FIG. **2** is a flow chart of an embodiment of a computer-implemented method for determining a fuel operating condition and monitoring an ASC assembly for catalyst deactivation.

DETAILED DESCRIPTION

One or more specific embodiments of the present invention will be described below. In an effort to provide a concise description of these embodiments, all features of an actual implementation may not be described in the specification. It should be appreciated that in the development of any such actual implementation, as in any engineering or design project, numerous implementation-specific decisions must be made to achieve the developers' specific goals, such as compliance with system-related and business-related constraints, which may vary from one implementation to another. Moreover, it should be appreciated that such a development effort might be complex and time consuming, but would nevertheless be a routine undertaking of design, fabrication, and manufacture for those of ordinary skill having the benefit of this disclosure.

When introducing elements of various embodiments of the present invention, the articles "a," "an," "the," and "said" are intended to mean that there are one or more of the elements. The terms "comprising," "including," and "having" are intended to be inclusive and mean that there may be additional elements other than the listed elements.

The present disclosure is directed to computer-implemented systems and methods for monitoring the fuel operating condition (e.g., lean fuel or rich fuel operating condition) of a combustion engine (e.g., reciprocating internal combustion engine or gas turbine engine), monitoring the deactivation (e.g., due to aging, thermal aging, and/or chemical poisoning) of catalysts in catalytic converters, and recommending corrective actions in response to detecting deactivated catalysts. In particular, embodiments of the present disclosures include an exhaust treatment (e.g., after-treatment) system configured to couple to the combustion engine and to treat emissions (e.g., in the engine exhaust) from the combustion engine (e.g., NO_X, HC, CO, etc.). The disclosed embodiments may be used to monitor and control any type of exhaust treatment system, such as catalyst based systems, chemical injection systems, or other types. The exhaust treatment system includes at least a first catalyst assembly (e.g., ASC assembly) that receives a fluid (e.g., treated exhaust flow or gases of the combustion engine) and converts NH_3 into molecular nitrogen (N_2) and CO into carbon dioxide (CO_2) and water. In certain embodiments, the exhaust treatment system includes a second catalyst assembly (e.g., TWC assembly) that initially treats the exhaust gases from the combustion engine prior to the first catalyst assembling receiving them. In certain embodiments, a fluid conduit is disposed between the TWC assembly and the ASC assembly that transfers (e.g., enables flow) of the fluid (e.g., treated exhaust gases) from the second catalyst assembly to the first catalyst assembly. An air or oxidant injection system (e.g., passive mid-bed air injection system) is coupled to the fluid conduit and injects an oxidant (e.g., air, O_2, oxygen-enriched air, or oxygen-reduced air) into the fluid conduit to regulate (e.g., maintain) a temperature of the fluid flowing into an inlet of the first catalyst assembly and to regulate catalytic activity in the first catalyst (e.g., conversion of NH_3 into N_2 and/or conversion of CO into CO_2 and water).

Multiple transducers or sensors (e.g., O_2 or lambda (λ) sensors and/or NO_X sensors) may be disposed throughout the exhaust treatment system. For example, at least one O_2 sensor is disposed upstream of an inlet of the first catalyst assembly (and upstream of the second catalyst assembly) that determines a concentration of O_2 in exhaust gases (e.g., prior to catalytic treatment) generated by the combustion engine. At least one NO_X sensor is disposed downstream of an outlet of the first catalyst assembly that measures an amount (e.g., concentration) of NO_X in the fluid (e.g., treated exhaust gases) exiting the outlet of the first catalyst assembly. A controller (e.g., air injection controller) is coupled to the air injection system. The controller receives signals from the multiple transducers representative of system parameters (e.g., concentration of O_2 in exhaust gases generated by the combustion engine and levels of NO_X in the fluid exiting the first catalyst assembly). The controller monitors the catalytic activity in the first catalyst assembly and determines whether the catalyst or catalytic activity in the first catalyst assembly has been deactivated (e.g., decreased in catalytic activity due to aging, thermal aging, and/or chemical poisoning). In certain embodiments, determining whether the catalyst has been deactivated may include determining if an amount or concentration of NO_X in the fluid is greater than a NO_X threshold value. Based on a determination that the catalytic activity in the first catalyst assembly (e.g., ASC assembly) has been deactivated, the controller may recommend a corrective action (e.g., cleaning of the first catalyst assembly). In certain embodiments, prior to determining whether the catalyst has been deactivated in the first catalyst assembly, the controller may determine the fuel operating engine condition of the combustion engine. For example, the controller may determine if the combustion engine is operating under a desired rich fuel condition by determining an air-to-fuel equivalence ratio value (e.g., λ value) for the exhaust gases generated by the combustion engine based at least on the concentration of O_2 (e.g., received from the at least one O_2 sensor) and to compare the air-to-fuel equivalence ratio to a threshold or reference air-to-fuel equivalence ratio value (e.g., λ reference) to determine if the air-to fuel equivalence ratio value is less than or equal to the threshold air-fuel equivalence ratio value. By diagnosing catalyst deactivation in the first catalyst assembly, emissions may be reduced and catalytic activity of the first catalyst assembly maximized.

Turning now to the drawings and referring to FIG. **1**, a schematic diagram of an exhaust treatment (e.g., after treatment) system **10** coupled to an engine **12** is illustrated. As described in detail below, the disclosed exhaust treatment system **10** monitors a fuel operating condition of the engine **12**. If the engine **12** is operating under a desired rich fuel condition (e.g., has an air-to-fuel equivalence value (λ value) of less than 1.0 such as approximately 0.999, 0.998, 0.997, 0.996, 0.995, 0.994, 0.993, 0.980, 0.970, 0.960, 0.950, or any other value less than 1.0), the disclosed exhaust treatment system **10** monitors the catalytic activity of a catalyst assembly (e.g., ASC assembly) for deactivation (e.g., decrease in catalytic activity due to aging, thermal aging, and/or chemical poisoning) of the catalysts. Also, the disclosed exhaust treatment system **10**, if catalytic deactivation is detected, provides a recommendation for corrective action (e.g., recommendation of cleaning the catalyst assembly). The engine **12** may include an internal combustion engine such as a reciprocating engine (e.g., multi-stroke engine such as two-stroke engine, four-stroke engine, six-stroke engine, etc.) or a gas turbine engine. The engine **12** may operate on a variety fuels (e.g., natural gas, diesel, syngas, gasoline, etc.). The engine **12** may operate as a lean-burn engine or a rich-burn engine. The engine **12** is coupled to an engine control unit (e.g., controller) **14** that controls and monitors the operations of the engine **12**. The engine control unit **14** includes processing circuitry (e.g., processor **16**) and memory circuitry (e.g., memory **18**). The processor **16** may execute instructions to carry out the operation of the engine **12**. These instructions may be encoded in programs or code stored in a tangible non-transitory computer-readable medium (e.g., an optical disc, solid state device, chip, firmware) such as the memory **18**.

During operation, the engine **12** generates combustion gases **20** used to apply a driving force to a component of the engine **12** (e.g., one or more pistons or turbines). The combustion gases **20** subsequently exit the engine **12** as an exhaust **20**, which includes a variety of emissions (e.g., NO_X, HC, CO, etc.). The exhaust treatment system **10** treats these emissions to generate milder emissions (carbon dioxide (CO_2), water, etc). As depicted, the exhaust treatment system **10** includes catalytic converters or catalysts assemblies such as the TWC assembly **22** and the ASC assembly **24**. In embodiments that include the TWC assembly **22** and the ASC assembly **24**, the engine **12** may be operated as a rich-burn engine (e.g., has λ value of less than 1.0 such as approximately 0.999, 0.998, 0.997, 0.996, 0.995, 0.994, 0.993, 0.980, 0.970, 0.960, 0.950, or any other value less than 1.0) to maximize the catalytic activity in both the TWC assembly **22** and the ASC assembly **24**. The TWC assembly **22**, via its catalytic activity, reduces NO_X via multiple reactions. For example, NO_X may be reduced via CO to generate N_2 and CO_2, NO_X may be reduced via H_2 to generate NH_3 and water, and NO_X may be reduced via a hydrocarbon (e.g., C_3H_6) to generate N_2, CO_2, and water. The TWC **22** assembly also oxidizes CO to CO_2, and oxidizes unburnt HC to CO_2 and water. A by-product of the reduction of NO_X in the TWC assembly is the emission of NH_3 as a result of ammonia slippage (e.g., due to unreacted NH_3). In certain embodiments, instead of the TWC assembly

22, any catalytic converter that reduces NO_X may be utilized. The ASC assembly **24**, via its catalytic activity (e.g., at zeolite sites), selectively reduces the NH_3 to N_2. In certain embodiments, the ASC assembly **24** also oxidizes CO to CO_2. An unaged (e.g., having complete catalytic activity) catalyst in the ASC assembly **24** generally converts all of the NH_3 to N_2. The ASC assembly **24** includes a catalyst operating window between upper and lower temperature thresholds, such as between approximately 400-510° C. The operating window represents a temperature where all of the NH_3 may be converted to N_2 and not oxidized to NO_X (assuming the catalytic activity has not been deactivated).

The TWC assembly **22** includes an inlet **26** to receive the exhaust **20** from the engine **12** and an outlet **28** to discharge a fluid **30** (e.g., treated engine exhaust). The ASC assembly **24** includes an inlet **32** to receive the fluid **30** (e.g., including the treated engine exhaust and/or injected oxidant (e.g., air, O_2, oxygen-enriched air, or oxygen-reduced air)) and an outlet **34** to discharge an additionally treated fluid **36**. A fluid conduit **38** is disposed between the TWC assembly **22** and the ASC assembly **24**. Specifically, the fluid conduit **38** is coupled to the outlet **28** of the TWC assembly **22** and the inlet **32** of the ASC assembly **24**, thus, coupling both assemblies **22**, **24** to enable fluid communication between them. The fluid conduit **38** enables the flow or transfer of the fluid **30** from the TWC assembly **22** to the ASC assembly **24**.

As depicted, an air or oxidant injection system **40** (e.g., passive mid-bed air injection system) is coupled to the fluid conduit **38**. The air injection system **40** injects oxidant (e.g., air, O_2, oxygen-enriched air, or oxygen-reduced air) into the fluid **30** within the fluid conduit **38** at a point or location **42** downstream of the outlet **28** of the TWC assembly **22** and upstream of the inlet **32** of the ASC assembly **24**. In certain embodiments, oxidant injection via the air injection system **40** may be actively driven via a pump or injector. In other embodiments, the air injection system **40** may occur via passive entrainment. For example, the air injection system **40** injects oxidant (e.g., air, O_2, oxygen-enriched air, or oxygen-reduced air) at a constant rate. The rate of injection may be determined empirically. The injection of oxidant (e.g., air, O_2, oxygen-enriched air, or oxygen-reduced air), via the air injection system **40**, regulates (e.g., maintains) a temperature of the fluid **30** (e.g., including the treated engine exhaust and/or injected oxidant (e.g., air, O_2, oxygen-enriched air, or oxygen-reduced air)) entering the ASC assembly **24** within the catalyst operating window of the ASC assembly **24** (e.g., with regards to conversion of NH_3 to N_2). The injection of oxidant also reduces emissions within the fluid **30**, **36** by reducing the NH_3 to N_2 and oxidizing CO to CO_2.

An air injection control unit **44** (e.g., processor-based controller) controls an amount of oxidant injected by the air injection system **40** to regulate (e.g., maintain) a temperature of the fluid **30** into the inlet **32** of the ASC assembly **24**. By controlling the temperature of the fluid, the air injection control unit **44** keeps the temperature of the fluid **30** entering the inlet **32** of the ASC assembly **24** at a desired temperature within the catalyst operating window (e.g., within upper and lower temperature thresholds) of the ASC assembly **24** to minimize emission of NO_X from the ASC assembly **24**. By maintaining the temperature of the fluid **30** within the catalyst operating window (where all of the NH_3 may be converted to N_2), the presence of NO_X in the fluid **36** exiting the ASC assembly **24** is utilized by the air injection control unit **40** to monitor the catalyst or catalytic activity of the ASC assembly **24** for deactivation (e.g., decrease in catalytic activity) and/or to recommend or indicate a need for corrective action (e.g., cleaning) on the ASC assembly **24**.

The exhaust treatment system **10** includes a plurality of transducers or sensors **46** disposed throughout the system **10** to measure systems parameters (e.g., O_2 concentration in exhaust gases generated by the engine **12**, emissions concentration (e.g., NO_X), etc.) and to provide feedback (e.g., via signals representative of the system parameters) to the air injection control unit **44** and/or the engine control unit **14**. For example, one or more O_2 or λ sensors **48** may be disposed downstream of the engine **12** and upstream of the TWC assembly **22** and the ASC assembly **24**. The one or more O_2 sensors **48** measure a concentration of O_2 in the exhaust gases generated by the engine **12** prior to treatment (e.g., via the catalytic activities of the TWC assembly **22** and the ASC assembly **24**). The transducers **46** also include one or more NO_X transducers **52** disposed adjacent or proximal (e.g., downstream of) the outlet **34** of the ASC assembly **24**. The NO_X transducer **52** measures an amount or level of NO_X (e.g., in ppm) in the fluid **36**.

Based at least on feedback from the one or more O_2 sensors **48**, the injection control unit **44** may determine if the engine **12** whether the engine is operating under a desired rich fuel condition (e.g., has λ value of less than 1.0 such as approximately 0.999, 0.998, 0.997, 0.996, 0.995, 0.994, 0.993, 0.980, 0.970, 0.960, 0.950, or any other value less than 1.0). The λ value represents the ratio of the actual air-fuel ratio to stoichiometry for a given mixture. A λ value of 1.0 is at stoichiometry, while a λ value of greater than 1.0 represents a lean fuel condition and a λ value less than 1.0 represents a rich fuel condition. The air injection control unit **44** may determine or calculate a λ value for the exhaust gases generated by the engine **12** based on the concentration of O_2 (e.g., received from at least one O_2 sensor **48**) and to compare the λ to a threshold or reference λ value (e.g., λ reference or λ_{REF}) to determine if the λ value is less than or equal to the λ_{REF}. The λ_{REF} represents a rich fuel condition threshold. The λ_{REF} is less than 1.0. For example, the λ_{REF} may be approximately 0.999, 0.998, 0.997, 0.996, 0.995, 0.994, 0.993, 0.980, 0.970, 0.960, 0.950, or any other value less than 1.0. The λ_{REF} may be empirically derived for the engine **12**. If the λ value is less than or equal to the λ_{REF}, then the engine **12** is operating under a desired rich fuel condition. If the engine **12** is operating under the desired rich fuel condition, then the injection control unit **44** may determine whether the catalytic activity of the ASC assembly **24** has been deactivated based on feedback from the one or more NO_X transducers **52**. Also, in certain embodiments, if the engine **12** is not operating under the desired rich fuel condition, the air control unit **44** may cease injection of the oxidant via the oxidant injection system **40** into the fluid conduit **38**.

In certain embodiments, based on feedback from the one or more O_2 sensors **48**, the engine control unit **14** may determine a fuel operating condition for the engine **12**. For example, the engine control unit **14** may calculate λ and determine whether the engine **12** is operating at stoichiometry, a rich fuel condition, or a lean fuel condition as described above. Based on determining the fuel operating condition, the operating parameters of the engine **12** may be adjusted. For example, the air-fuel ratio may be adjusted to change fuel operating condition to a desired fuel operating condition.

Based on feedback from the one or more NO_X transducers **52**, the air injection control unit **44** monitors for (e.g., diagnoses or detects) deactivation of the catalyst (e.g., catalytic activity) within the ASC assembly **24**. For example, the air injection control unit **44** may compare the level (e.g., value) of NO_X (e.g., nitrogen monoxide and nitrogen dioxide) obtained from the transducer **52** to a NO_X threshold value to determine if deactivation of the catalyst of the ASC assembly

24 has occurred (e.g., if the level of measured NO_X is greater than the NO_X threshold value or reference value, $NO_{X\ REF}$). The NO_X threshold value may be determined empirically. If the catalytic activity of the ASC assembly **24** is deactivated, the air injection control unit **44** may recommend or indicate a need for corrective action to rejuvenate the catalytic activity of the ASC assembly **24**. For example, the corrective action may include cleaning (e.g., physical cleaning), chemical treatment, drying, and/or calcining. The air injection control unit **44** may provide a user-perceptible signal indicating the need for the corrective action. For example, a textual or visual indicator may be provided to a display of the control unit **44** or a display on remote device. Also, a visual (e.g., via a light emitting device such as an LED) or audible signal (e.g., via a speaker) may be provided on the control unit **44** or a remote device.

The air injection control unit **44** includes processing circuitry (e.g., processor **54**) and memory circuitry (e.g., memory **56**). The processor **54** may execute instructions to monitor system parameters (fuel operating condition (e.g., rich fuel condition), emissions levels (e.g., NO_X), etc.), regulate (e.g., maintain) the temperature of the fluid **30** entering the inlet **32** of the ASC assembly **24**, and/or monitor the catalyst of the ASC assembly **24** for deactivation. These instructions may be encoded in programs or code stored in a tangible non-transitory computer-readable medium (e.g., an optical disc, solid state device, chip, firmware) such as the memory **56**. The processor **54** may also access tables or values stored in the memory **56**. For example, the memory **56** may store one or more λ_{REF} values. The memory **56** may also store one or more NO_X threshold values. The memory **56** may also store one or rates of injection of oxidant for the passive air injection system **40** (e.g., for the constant rate of injection). As depicted, the air injection control unit **44** is coupled to the engine control unit **14**. In certain embodiments, the air control unit **44** and the engine control unit **14** may form a single control unit.

FIG. **2** is a flow chart of an embodiment of a computer-implemented method **58** for determining a fuel operating condition of the engine **12** and monitoring a catalyst assembly (e.g., ASC assembly) for catalyst deactivation. All or some of the steps of the method **58** may be executed by the air injection control unit **44** (e.g., utilizing the processor **18** to execute programs and access data stored on the memory **56**). The method **58** includes determining λ_{REF} for analyzing the exhaust gases from the engine **12** prior to treatment with any catalysts (e.g., the TWC assembly **22** and/or the ASC assembly **24**) (block **60**). In certain embodiments, the value for λ_{REF} may be obtained from the air injection control unit **44** (e.g., memory **56**) or the engine control unit **14** (e.g., memory **18**). Alternatively, the λ_{REF} may be inputted by a user. The λ_{REF} represents a rich fuel condition threshold. The λ_{REF} is less than 1.0. For example, the λ_{REF} may be approximately 0.999, 0.998, 0.997, 0.996, 0.995, 0.994, 0.993, 0.980, 0.970, 0.960, 0.950, or any other value less than 1.0. The $\lambda_{PRE\text{-}CAT}$ may be empirically derived for the engine **12**. The method **58** also includes determining the actual λ value ($\lambda_{PRE\text{-}CAT}$) of the exhaust gases from the engine **12** prior to treatment with any catalysts (block **62**). For example, the air injection control unit **44** may calculate $\lambda_{PRE\text{-}CAT}$ based on at least feedback from one or more O_2 sensors **48** as described above.

The method **58** further includes comparing $\lambda_{PRE\text{-}CAT}$ to λ_{REF} to determine a fuel operating condition of the engine **12** (block **64**). Specifically, the method **58** includes determining whether $\lambda_{PRE\text{-}CAT}$ is less than or equal to λ_{REF}. If $\lambda_{PRE\text{-}CAT}$ is not less than or equal to λ_{REF}, then the engine **12** is not operating under the desired fuel rich condition, and the method **58** includes ceasing oxidant injection (block **66**) and continuing to determine $\lambda_{PRE\text{-}CAT}$ (block **62**).

If $\lambda_{PRE\text{-}CAT}$ is less than or equal to λ_{REF}, the engine **12** is operating under the desired rich fuel condition. Then, the method **58** shifts to determining whether the catalytic activity of the ASC assembly **24** has been deactivated by first measuring the level of NO_X ($NO_{X,\ ASC\ OUT}$), via one or more NO_X sensors **52**, in the fluid **36** (e.g., additionally treated exhaust gases) exiting the outlet **34** of the ASC assembly **24** (block **68**). The method **58** determines if $NO_{X,\ ASC\ OUT}$ is greater than a NO_X threshold value **70** ($NO_{X\ REF}$) (block **72**). The NO_X threshold value **70** may be obtained from the memory **56**. Also, the NO_X threshold value **70** may be inputted by a user. The NO_X threshold value **70** may be empirically derived when initially setting up the ASC assembly **24**. If $NO_{X,\ ASC\ OUT}$ is not greater than the NO_X threshold value **70**, the method **58** returns to measuring $NO_{X,\ ASC\ OUT}$ (block **68**) and comparing $NO_{X,\ ASC\ OUT}$ to the NO_X threshold value **70** (block **72**). If $NO_{X,\ ASC\ OUT}$ is greater than the NO_X threshold value **70**, the method **58** determines that the catalytic activity or catalyst of the ASC assembly **24** is deactivated (block **74**). Based on determining catalyst deactivation of the ASC assembly **24**, the method **74** recommends or indicates a need for corrective action to rejuvenate (e.g., reactivate) the ASC assembly **24** (block **76**). For example, the air injection control unit **44** causes a user perceptible signal (e.g., via a computer display) as described above to be provided to indicate the need for corrective action. Corrective actions may include cleaning (e.g., physical cleaning), chemical treatment, drying, and/or calcining.

Technical effects of the disclosed embodiments include providing computer implemented systems and methods for monitoring the fuel operating condition (e.g., for a desired rich fuel operating condition) of the engine, monitoring the deactivation of catalysts in catalytic converters (e.g., ASC assembly **24**), and recommending corrective actions (e.g., cleaning) in response to detecting deactivated catalysts. In particular, embodiments include the exhaust treatment system **10** that includes at least one O_2 sensor **48** disposed upstream of TWC assembly **22** and the ASC assembly **24** that measures O_2 concentration in the exhaust gases generated by the engine **12** prior to catalytic treatment. Based on at least the feedback from the at least one O_2 sensor **48**, the air injection control unit **44** may determine whether the engine **12** is operating at a desired rich fuel condition. The system **10** also includes at least one NO_X transducer **52** downstream of the outlet **34** of the ASC assembly **24** to provide feedback to the air injection control unit **44** as to the level of NO_X emissions in the fluid **36**. If the engine **12** is operating at the desired rich fuel condition, based on the level of NO_X emissions, the air injection control unit **44** can determine if the catalyst in the ASC assembly **24** has deactivated, and, if the catalyst has deactivated, the control unit **44** may recommend or indicate a need for corrective action to rejuvenate the catalytic activity of the ASC assembly **24**. By diagnosing whether the catalyst of the ASC assembly **24** has deactivated, the catalytic activity of the ASC assembly **24** may be maximized and emissions reduced.

This written description uses examples to disclose the invention, including the best mode, and also to enable any person skilled in the art to practice the invention, including making and using any devices or systems and performing any incorporated methods. The patentable scope of the invention is defined by the claims, and may include other examples that occur to those skilled in the art. Such other examples are intended to be within the scope of the claims if they have structural elements that do not differ from the literal language of the claims, or if they include equivalent structural elements with insubstantial differences from the literal language of the claims.

The invention claimed is:

1. A system, comprising:

an exhaust aftertreatment system configured to treat emissions from a combustion engine, wherein the exhaust aftertreatment system comprises:

a three-way catalyst (TWC) assembly having a first inlet;

an ammonia slip catalyst (ASC) assembly configured to receive treated exhaust gases from the TWC assembly and to convert ammonia (NH_3) within the treated exhaust gases into nitrogen (N_2), wherein the ASC assembly has a second inlet and an outlet;

at least one oxygen (O_2) sensor disposed upstream of the first inlet of the TWC assembly and configured to determine a concentration of O_2 in exhaust gases generated by the combustion engine;

at least one nitrogen oxides (NO_x) sensor disposed downstream of the outlet of the ASC assembly and configured to measure a concentration of NOx in the treated exhaust gases exiting the outlet of the ASC assembly; and

a controller comprising a memory encoding one or more processor-executable routines and a processor configured to access and execute the one or more routines encoded by the memory, wherein the routines, when executed cause the processor to receive a first signal from the at least one NO_x sensor representative of the concentration of NO_x in the treated exhaust gases exiting the outlet of the ASC assembly and a second signal from the at least one O_2 sensor representative of the concentration of O_2 in the exhaust gases generated by the combustion engine, and to determine whether the catalytic activity has been deactivated in the ASC assembly based at least in part on the received first and second signals or by determining if the concentration of NO_x in the treated exhaust gases exiting the ASC assembly is greater than a NO_x threshold value, and wherein the controller is configured to determine whether corrective action is needed to clean the ASC assembly to reactivate the catalytic activity if it is determined that the catalytic activity in the ASC assembly has been deactivated, and to cause a user perceptible signal to be provided indicating the need for corrective action.

2. The system of claim 1, wherein the exhaust aftertreatment system comprises a fluid conduit disposed between the TWC assembly and the ASC assembly and configured to transfer the treated exhaust gases from the TWC assembly to the ASC assembly.

3. The system of claim 2, wherein the exhaust aftertreatment system comprises an oxidant injection system coupled to the fluid conduit and configured to inject an oxidant at a constant rate into the fluid conduit to maintain a temperature of the treated exhaust gases flowing into the inlet of the ASC assembly and to reduce emissions in the treated exhaust gases.

4. The system of claim 1, wherein the controller is configured, prior to determining whether the catalytic activity in the first catalyst ASC assembly has been deactivated, to determine if the combustion engine is operating under a desired rich fuel condition and to subsequently determine whether the catalytic activity in the catalyst ASC assembly has been deactivated if the combustion engine is operating under the desired rich fuel condition.

5. The system of claim 4, wherein the controller is configured to determine an air-to-fuel equivalence ratio value for the exhaust gases generated by the combustion engine based on the concentration of O_2 in the exhaust gases and to determine if the combustion engine is operating under the desired rich fuel condition if the air-to-fuel equivalence ratio value is less than or equal to a threshold air-to-fuel equivalence ratio value.

6. The system of claim 1, comprising the combustion engine coupled to the exhaust aftertreatment system.

7. The system of claim 1, comprising a display, wherein the controller is configured to cause user perceptible signal to be provided on the display.

8. A system, comprising:

a controller comprising a memory encoding one or more processor-executable routines and a processor configured to access and execute the one or more routines encoded by the memory, wherein the routines, when executed cause the processor to determine if a combustion engine is operating under a desired rich fuel condition, and, if the combustion engine is operating under the desired rich fuel condition, to monitor a catalytic activity within an ammonia slip catalyst (ASC) assembly disposed downstream of a three-way (TWC) catalyst that converts (NH_3) within treated exhaust gases from the TWC catalyst into nitrogen (N_2) to determine whether the catalytic activity has been deactivated in the ASC assembly, and wherein the controller is configured to determine whether corrective action is needed to clean the ASC assembly to reactivate the catalytic activity if it is determined that that the catalytic activity in the ASC assembly has been deactivated and to cause a user perceptible signal to be provided indicating the need for corrective action.

9. The system of claim 8, wherein the controller is configured to receive a first signal from at least one oxygen (O_2) sensor disposed upstream of an inlet of the ASC assembly, wherein the first signal is representative of a concentration of O_2 in exhaust gases generated by the combustion engine.

10. The system of claim 9, wherein the controller is configured to determine the fuel condition the combustion engine is operating under by determining an air-to-fuel equivalence ratio value for the exhaust gases generated by the combustion engine based on the concentration of O_2 in the exhaust gases and to determine if combustion engine is operating under the desired rich fuel condition by determining if the air-to-fuel equivalence ratio value is less than or equal to a threshold air-to-fuel equivalence ratio value.

11. The system of claim 9, wherein the controller is configured to receive a second signal from at least one nitrogen oxides (NO_X) sensor disposed downstream of an outlet of the ASC assembly, wherein the second signal is representative of a concentration of NO_X in the treated exhaust gases exiting the outlet of the ASC assembly.

12. The system of claim 11, wherein the controller is configured to determine whether the catalytic activity in the ASC assembly has been deactivated by determining if the concentration of NO_X in the treated exhaust gases is greater than a NO_X threshold value.

13. The system of claim 8, comprising an exhaust aftertreatment system having the controller, wherein the exhaust aftertreatment system comprises the ASC assembly and an oxidant injection system coupled to a fluid conduit upstream of an inlet to the ASC assembly and configured to inject an oxidant at a constant rate into the fluid conduit to maintain a temperature of the treated exhaust gases flowing into the inlet of the ASC assembly and to reduce emissions in the treated exhaust gases.

14. The system of claim **8**, comprising a display, wherein the controller is configured to cause the user perceptible signal to be provided on the display.

15. A system, comprising:

an exhaust aftertreatment system configured to treat emissions from a combustion engine, wherein the exhaust aftertreatment system comprises:

a three-way catalyst (TWC) assembly having a first inlet;

an ammonia slip catalyst (ASC) assembly configured to receive treated exhaust gases from the TWC assembly and to convert ammonia (NH_3) within the treated exhaust gases into nitrogen (N_2), wherein the ASC assembly has a second inlet and an outlet;

at least one oxygen (O_2) sensor disposed upstream of the first inlet of the TWC assembly and configured to determine a concentration of O_2 in exhaust gases generated by the combustion engine;

at least one nitrogen oxides (NO_x) sensor disposed downstream of the outlet of the ASC assembly and configured to measure a concentration of NO_x in the treated exhaust gases exiting the outlet of the ASC assembly; and

a controller comprising a memory encoding one or more processor-executable routines and a processor configured to access and execute the one or more routines encoded by the memory, wherein the routines, when executed cause the processor to determine if the combustion engine is operating under a desired rich fuel condition based on the concentration of O_2 in the exhaust gases, and, if the combustion engine is operating under the desired rich fuel condition, utilizing the measured concentration of NO_x in the treated exhaust gases exiting the outlet of the ASC assembly to monitor the catalytic activity within the ASC assembly that converts NH_3 within the treated exhaust gases into N_2 to determine whether the catalytic activity has been deactivated in the ASC assembly, and wherein the controller is configured to determine whether corrective action is needed to clean the ASC assembly to reactivate the catalytic activity if it is determined that that the catalytic activity in the ASC assembly has been deactivated and to cause a user perceptible signal to be provided indicating the need for corrective action.

16. The system of claim **15**, comprising a display, wherein the controller is configured to cause the user perceptible signal to be provided on the display.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 9,228,469 B2
APPLICATION NO. : 14/252890
DATED : January 5, 2016
INVENTOR(S) : Devarakonda

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

On the Title Page, in item (54), in Title, in Column 1, Line 1, delete "AFTERTREATEMENT" and insert -- AFTERTREATMENT --, therefor.

In the Specification

In Column 1, Line 1, delete "AFTERTREATEMENT" and insert -- AFTERTREATMENT --, therefor.

In the Claims

In Column 9, Line 62, in Claim 4, delete "first catalyst ASC" and insert -- ASC --, therefor.

In Column 9, Line 65, in Claim 4, delete "catalyst ASC" and insert -- ASC --, therefor.

In Column 10, Line 30, in Claim 8, delete "that that" and insert -- that --, therefor.

In Column 12, Line 17, in Claim 15, delete "that that" and insert -- that --, therefor.

Signed and Sealed this
Twenty-third Day of August, 2016

Michelle K. Lee

Michelle K. Lee
Director of the United States Patent and Trademark Office